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DOI: -

To appear in : BIOTROPIA Issue

Received date : 12 February 2018

Accepted date : 11 February 2019

This manuscript has been accepted for publication in BIOTROPIA journal. It is unedited, thus, it will undergo the final copyediting and proofreading process before being published in its final form.

USE OF LANDSAT IMAGERY TO MAP SPREAD OF THE INVASIVE ALIEN SPECIES *Acacia nilotica* IN BALURAN NATIONAL PARK, INDONESIA

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Running title: Landsat analysis of invasive alien species *Acacia nilotica* distribution

ABSTRACT

Acacia nilotica was introduced to Baluran National Park in the late 1960s to create fire breaks which would prevent fire spreading from Baluran Savanna to the adjacent teak forest. However, *A. nilotica* has spread rapidly and is threatening the existence of Baluran Savanna as it has been observed to cause a ecosystem transition from open savanna to a closed canopy of *A. nilotica* in some areas. This study is one of a few that examines *A. nilotica* invasion in Baluran National Park through remote sensing. Land cover dynamics were quantified using a supervised classification approach on Landsat 7 and 8 multi-spectral images. Results showed that savanna and *A. nilotica* can be recognized using a composite of bands 6, 5 and 3 of the Landsat 8 image. Across a 14 year period (2000-14), *A. nilotica* has spread far north and south from its original introduction location, invading not only savannas but also dry forests in the Baluran National Park. The savanna size has decreased by 1,361 ha, meanwhile the *A. nilotica* stand has increased by 1,886 ha over this period. Spatial distribution of *A. nilotica* in Baluran National Park shows a clumped pattern. *Acacia nilotica* which develops into a homogeneous stand in the north-west and eastern parts of the national park occupied an area of 3,628 ha or about 14.5% of the total area. This study has demonstrated that remote sensing technology can be effectively used to estimate the patterns of distribution and amount of *A. nilotica* cover change over the whole Baluran National Park. This is one of the advantages of remote sensing and GIS, where as it is difficult and expensive to make such direct assessments using the conventional approach of field survey and vegetation analysis.

Keywords: *Acacia nilotica*, Baluran National Park, remote sensing, supervised classification

INTRODUCTION

The role of remote sensing (RS) and geographical information systems (GIS) in fire and vegetation management has been recognized with studies involving mapping and analysing fire history now commonplace (Arno*et al.* 1977; Chuvieco & Congalton 1989; Van Wilgen*et al.* 2000; Keane*et al.* 2001; Verlinden & Laamanen 2006). For instance, a sequence of fire scars was developed using all available Landsat images between 1989 and 2001 in north-east Namibia to investigate the relationship between fire frequency, rainfall, and land cover (Verlinden & Laamanen 2006). Van Etten (1998) used a GIS for predictive vegetation mapping using models that linked vegetation units to map environmental variables across the extensive remote areas in Australia. Furthermore, a connection between the three main ecological strategies of plants and their canopy reflectance were set up by Schmidtlein*et al.* (2012) to test whether remote sensing was capable of capturing the spatial pattern of plant strategy types. His study showed that all three primary strategy types could be mapped using remote sensing. There has been considerable amount of studies on the use of RS/GIS in savanna ecosystems (Stroppiana *et al.*2003; Chacón-Moreno 2004; Hudak & Brockett 2004; Sano *et al.* 2010), on the other hand less studies have addressed the use of RS/GIS in mapping invasive alien plant species, especially in savanna-dominated landscapes.

Figure 1. Stand of *Acacia nilotica* in Bekol Savanna Baluran National Park, Indonesia

Acacia Mill. is the main genus in the Leguminosae-Mimosoideae with roughly 1,200 species distributed mostly in tropical and subtropical regions (Mabberley 1997; Abari*et al.* 2012). *Acacia nilotica* is a dominant colonizer in many parts of the world including protected areas such as Baluran National Park in East Java Province, and Wasur National Park in Papua (Tjitrosoedirdjo 2008; Padmanaba*et al.* 2017). Baluran National Park covers vast area of 25,000 ha and mostly consists of savanna and dry forest. The exotic species *A. nilotica* was introduced into Baluran National Park in the late 1960s to create fire breaks to prevent fires spreading from Baluran Savanna into the adjacent teak forest. However, at present *A. nilotica* has spread rapidly and threatening the existence of Baluran Savanna and changing these open savannas into closed canopies of *A. nilotica* in some areas (Figure 1) (Barata 2000; Djufri 2004). This change in condition could threaten the large mammals of Baluran Savanna such as barking deer (*Muntiacus muntjak*), sambar deer (*Cervus unicolor*) and banteng or wild ox of Java (*Bos javanicus*) due to the loss of browsing and grazing fields (Sabarno 2002).

This study is one of the few studies of its kind that examines *A. nilotica* invasion in Baluran National Park through remote sensing. Setiabudi *et al.* (2013) conducted a spatial analysis of *A. nilotica* invasion in Baluran National Park, covering areas of the national park. However, the study was not based on Landsat images and did not provide information of *A. nilotica* coverage change. Caesariantika *et al.* (2011) and Djufri (2012) conducted field study of *A. nilotica* in Baluran National Park, which partly took place in Bekol savanna, however these studies ignored the capabilities of remote sensing analysis. Whereas Siswoyo (2014) used Landsat images in a study in Baluran National Park, but the assessment was only on one particular year with also no information on *A. nilotica* cover changes. Sutomo *et al*. (2016) conducted combined field and GIS study that provided information about the changes in *A. nilotica* stands but only covering the Bekol savanna area. Therefore, the objectives of this paper were to provide information on the distribution of invasive alien species (IAS) of *A. nilotica* over the whole Baluran National Park using Landsat images analysis and to calculate changes in savanna and *A. nilotica* covers following 14 years of invasion (2000 – 2014).

MATERIALS AND METHODS

Baluran is located at the north-east tip of East Java, and is a low plateau in the rain shadow of mountain ranges. The area has been used for hunting since the 1900s. In 1937, the Dutch Government proclaimed this area as a wildlife reserve (decree GB. No. 9 dated 25 September 1937 Stbl. 1937 No. 544) to conserve large mammals, mainly wild ox of Java, also known as banteng (*Bos sundaicus*), that had already inhabited the surrounding areas. This decree was then reinstated by the Indonesian Agriculture Minister in 1962 (decree No. SK/II/1962 dated 11 May 1962) and then it was proclaimed as a national park in 1980. Baluran National Park covers a vast area of 25,000 ha and it is located in Situbondo District, East Java Province. Its northern part is bordered by the Madura Strait and on its eastern side is bordered by the Bali Strait.

Satellite images for Baluran National Park (year 2000 and year 2014) were downloaded from Landsat 8 and Landsat 7 (http://earthexplorer.usgs.gov/) path 117, row 065. The images downloaded were selected because they were either were not covered by clouds or with minimal amounts of the cloud cover and had level 9 image quality (no errors detected, perfect scene). Images were both selected in the middle of the dry season when differences between forest and savanna would likely be more acute. Details of downloaded images can be seen in Table 1.

Table 1. Details of images downloaded for remote sensing analysis.

Images	Landsat Satellite	Date acquired	Spatial Resolution	Image quality	Path/ Row	Cloud cover	Total band	Image band	Sensitivity

			(meters)			(%)		stacked	
1	7	07/09/ 2000	30	9	117/0 65	25.83	8	2(G) 4 (NIR-1) 5 (NIR-2)	8 bit/pixel
2	8	12/10/ 2014	30	9	117/0 65	19.43	11	3 (G), 5 (NIR) 6 (SWIR-1)	12 bit/pixel

Note: G; Green, NIR; Near-Infrared, SWIR:Shortwave Infrared

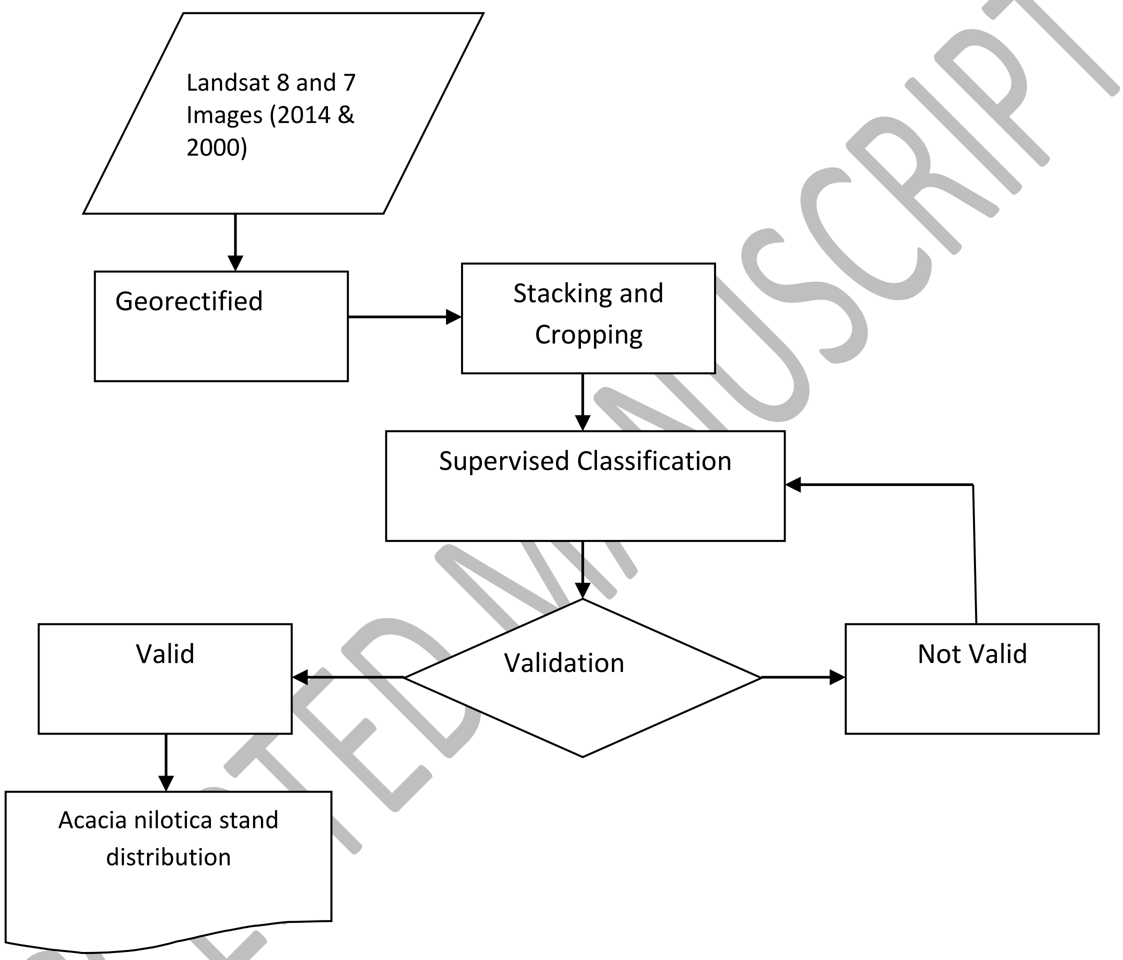


Figure 2. Flowchart showing steps in spatial analysis of *Acacia nilotica* in Baluran National Park. Modified from Siswoyo (2014).

Ground survey was done in October 2014 with a total 60 sites which were placed randomly in three different vegetation types, namely savanna, dry forest, and *A. nilotica* stand. Presence-absence of *A. nilotica* was recorded and geographical position was marked at the centre of each plot with a GARMIN handheld GPS. Landsat images were georectified to reduce geometric distortion. The bands6 (1.57 - 1.65 µm), 5 (0.85 - 0.88 µm) and 3 (0.53 - 0.59 µm)were then usedfor the Landsat 8 while for the Landsat 7 the bands of 5 (1.55 - 1.75 µm), 4 (0.77 - 0.90 µm) and 2 (0.52 - 0.60 µm) were chosen and each of them were composited into the RGB (Red-Green-Blue) image system. These bands were chosen as they are widely used and recommended to map contrasting vegetation types (such as savanna and forest; Barsi*et al.* 2014). These results were then loaded as RGB image and used as the basis for classification (Figure 2). After layer stacking, the image was cropped so as to include the whole Baluran National Park area. Pan-sharpening was then processed using band 8 panchromatic to enhance and sharpen the composite images facilitating determination the region of interest on classification since it has a more detailed spatial resolution.

Classification of savanna, forest and *A. nilotica* stand were conducted using supervised classification via a maximum likelihood approach within ENVI 4.5with the field plot data used as training sites (Richards 1999). The classification results (map) were validated by comparing them with ground survey points and were also checked using Google Earth and field observations, and were found to be of acceptable accuracy (see results). Once the classification was finished, each class was then converted to individual layer and saved as a shape file to be analysed in ArcGIS 10.1. The data layers were projected into datum WGS 1984, with the map projection being Universal Transverse Mercator, Zone 49South. The size of each area/class was then calculated in ArcGIS for each image (year 2000 and 2014) to obtain quantitative information on the coverage of various land cover types and the change in *A. nilotica* cover in Baluran National Park over the 14 year study period.

RESULTS AND DISCUSSION

Savanna was clearly shown in the image as mix of bright glossy white and light to semi-dark purple-ish colours (Figure 3). *Acacia nilotica* stands were represented as mix of semi-dark green and light to dark brown on the map. The spatial pattern of *A. nilotica* vegetation cover on the image consisted of a low density of green spots on a light brown background because it was influenced by the open leaf architecture on the *A. nilotica* trees occurring over dry grass or exposed soil of the underlying savanna (images were from the dry season when grasses are cured or dead). Overall (total) accuracy of the classification was 83% (Table 2).In terms of user accuracy (proportion of map predictions which were correct), the highest was *A. nilotica* stand (88%). In terms of producer accuracy (the proportion of reference sites accurately predicted by the map), the highest was savanna (100%) followed by *A. nilotica* stand (83%) and dry forest (75%).

Table 2. Accuracy test of the produced map

Sat. Image / Field	*Acacia nolitica* stand	Savanna areas	Dry Forest	Total	UA (%)	PA (%)	OE (%)	KE (%)	Mapping Accuracy (%)
Acacia nilotica stand	15	0	2	17	0.88	0.83	0.12	0.17	0.87

Savanna areas	1	7	2	10	0.10	1.00	0.30	0.00	0.68
Dry Forest	2	0	12	14	0.14	0.75	0.14	0.25	0.83
Total	18	7	16	41					0.83

Note: UA = user's accuracy, PA = producer's accuracy, OE = ommision's error, KE = commission's error

In the year 2000, *A. nilotica* mainly occurred around the Bekol Savanna area and its surrounds (Figure 4). Fourteen years later, *A. nilotica* has spread far north and also south of the national park areas, invading not only savannas, but also dry forests (Figure 4). Over the same period, the savanna size decreased from approximately 6,510 ha in 2000 to 5,149 ha in 2014 (a decline of 1,361 ha) (Figure 5). In contrast, the *A. nilotica* stand area has increased by around 1,886 ha (from 1,742 ha in 2000 to 3,628 ha in 2014, an108% increase) (Figure 5). The spatial distribution of *A. nilotica* over the whole Baluran National Park shows a highly clumped pattern (Figure 4), occurring as patches of dense stands in distinct parts of the park. Landsat 8 image analysis for October 2014 indicated that *A. nilotica* grows as homogeneous stand in north-west and eastern parts of the national park (Figure 6). In 2014, A. *nilotica* occupied an area of 3,628 ha, equal to 14.5% of Baluran National Park total area.

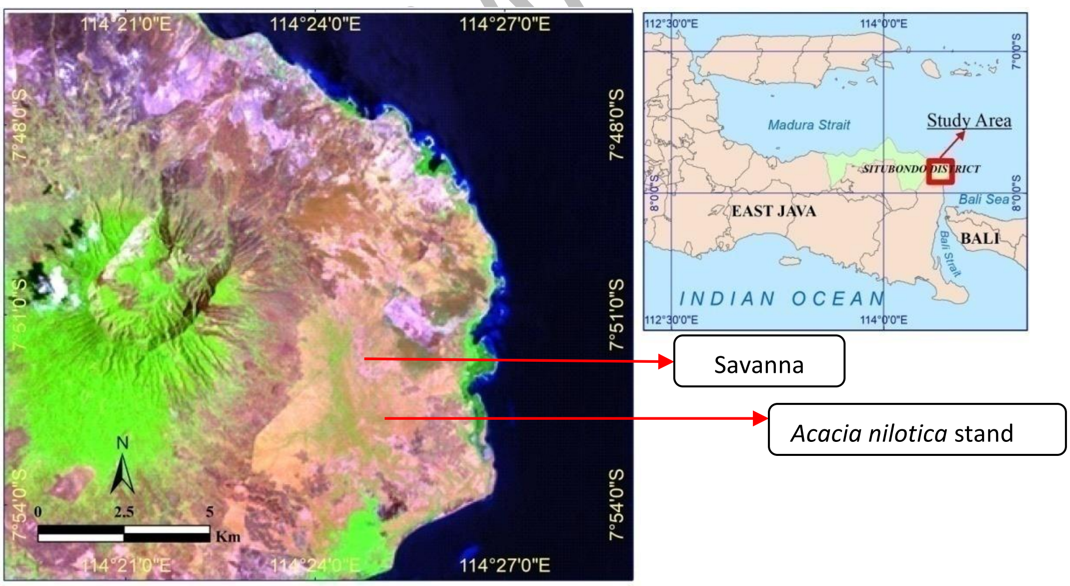
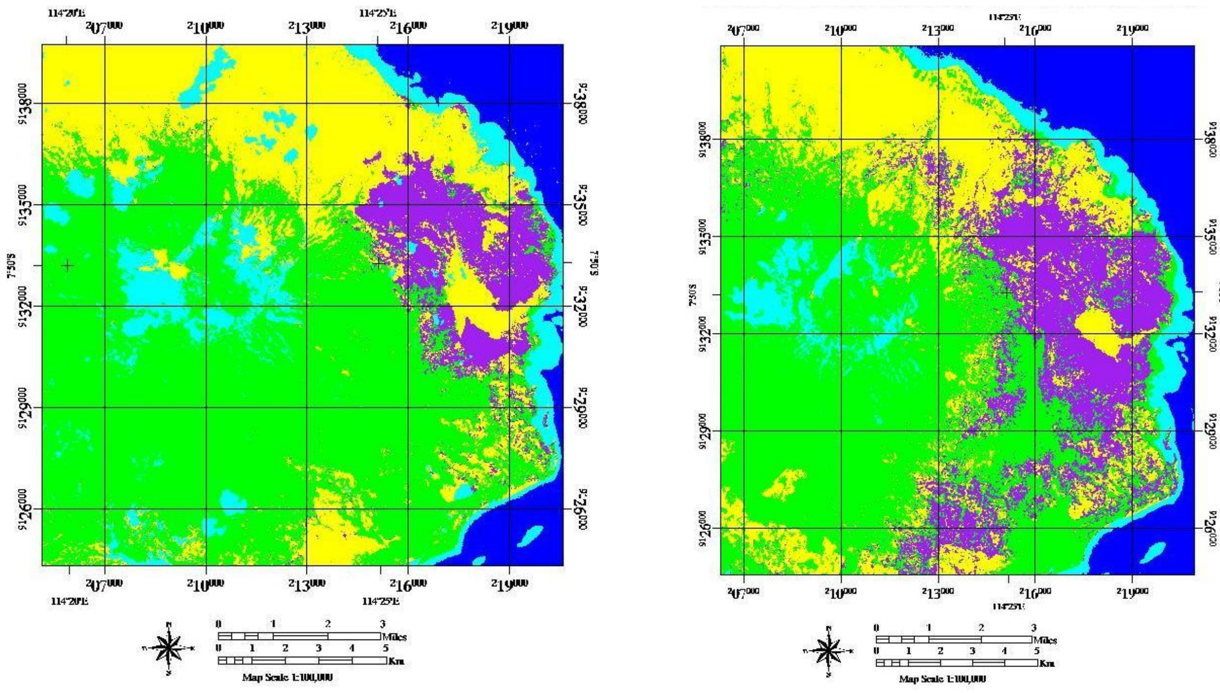


Figure 3. Different colour and pattern of savanna and distinct *Acacia nilotica* stand was shown in this combination of band 6, 5 and 3 of Landsat 8 image of Baluran National Park, 2014.



a b

Figure 4. Expansion of *Acacia nilotica* stands in Baluran National Park over14 years. Left (a) – *A. nilotica* distribution in year 2000, right (b) - *A. nilotica* distribution in 2014. Yellow area in the middle is Bekol savanna area, purple area is *A. nilotica* area and green colour is forest.

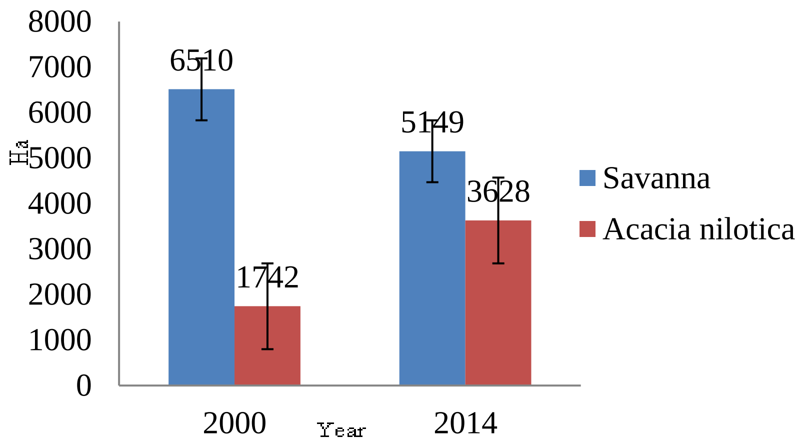


Figure 5. Changes in area size (data extracted from the created map) for savanna and *Acacia nilotica* stand between year 2000 and 2014 in Baluran National Park.

The estimated area of the *A. nilotica* stand in this study is likely to be smaller than actual occurrence in the field, and this is reflected in the accuracy assessment data shown above. This is because Landsat images cannot identify *A. nilotica* that grows individually or in small clumps that may be smaller than the Landsat image pixel size. The pixel size of the Landsat images is 30 m x 30 m, which means that only vegetation type or *A. nilotica* stand that has the size at least 500 m^2 can be detected as one pixel (Siswoyo 2014). If it is 500 m^2 out of 900 m^2 (the pixel size), it will be the dominant type and therefore will be classified as *A. nilotica*. In other words, *A. nilotica* needs to be the dominant cover type in a pixel for it to be recognised as *A. nilotica* cover.

Using remote sensing analysis, a supervised classification of Landsat image from the year 2000 and 2014 shows a decrease in savanna areas and corresponding increase of *A. nilotica* stand in Baluran National Park. It is clear from the analysis that *A. nilotica* has spread rapidly over the 14 years and has mainly invaded areas of savanna. Also thickening of *A. nilotica* over this period has converted much of this savanna vegetation into dense stands of *A. nilotica*. *Acacia nilotica* now grows in a structurally homogeneous and mostly single-species stand in north-west and eastern parts of the national park. In the year 2000, A. *nilotica* mainly occurred in a lowland area around the Bekol Savanna area and its surrounds. Fourteen years later *A. nilotica* spread far north and also south of the national park areas, invading not only savannas but also dry forests.

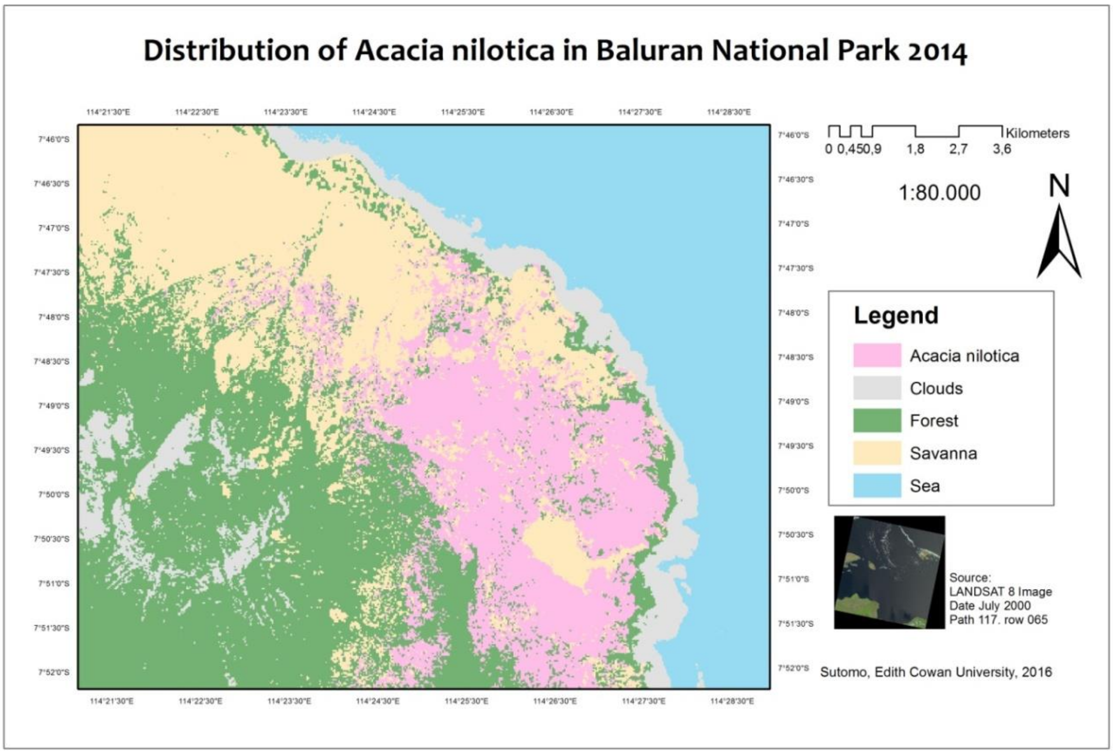


Figure 6. Distribution of *Acacia nilotica* stands in 2014, in Baluran National Park.

Acacia nilotica was first planted in Bekol Savanna area in the 1960s (Siswoyo 2014). In a study using field mapping and spatial analysis in GIS, it was found that in one-year period the savanna area in Bekol Savanna had been decreased due to invasion of 85 ha new *A. nilotica* stands (Sutomo*et al.*2016). These newly expanded areas were mainly comprised of *A. nilotica* saplings and seedlings. This area also contained other less dominant woody species such as *Azadirachta indica, Ziziphus rotundifolia*, *Thespesia lampas*, *Polytrias amaura* and *Dichanthium coricosum*. There had been few reports that noted other locations where *A. nilotica* had been expanding, such as in

Balanan, Kramat and Curah Udang (Sabarno 2002; Djufri 2004; Setiabudi*et al.* 2013; Siswoyo 2014).

Besides dry forest, the lowland savanna area is an important habitat for large mammal grazers, such as wild buffalo, deer and wild ox of Java (also known as banteng). Invasion of *A. nilotica* in these areas is likely to lead to changes in the feeding behaviour of these grazers and may be responsible for the spread of this invasive species further in the national park. *Acacia nilotica* is mostly unpalatable to these herbivores as this plant possesses thorny spikes on branches which make it difficult for the herbivores to consume the leaves. However, the pods that drop to the ground are usually consumed by herbivores during the prolonged dry period when fresh shoots of grasses and other herbs are scarce. At the end of the wet season toward the dry season, mature *A. nilotica* pods drop from the trees and are consumed by herbivores such as water buffalo that spread *A. nilotica* further in the national park (Sutomo*et al.* 2015; Tjitrosoedirdjo*et al.* 2013). Sutomo*et al.* (2015) found that there was a vast amount of seeds found in buffalo stools, with approximately 166 seeds of *A. nilotica* found per 100 g of buffalo stools/faecal dropping.

This study has actually demonstrated that remote sensing technology can be used to effectively and accurately quantify patterns of vegetation distribution and changes in the area of *A. nilotica* cover in Baluran National Park. The technique is likely to be suitable for mapping and quantifying other woody plant invasion into savanna ecosystems. This study showed the advantages of remote sensing and GIS as they require fewer resources and are less demanding method for invasive species studies compared to the conventional approach of field vegetation survey and analysis (van Etten 1998; Van Etten&Fox 2004). Remote sensing and GIS have been also used in Indonesia and a range of literature has demonstrated the use of remote sensing and the available tools in GIS for various ecological studies such as for habitat suitability (Gamasari 2007), land use and cover change (Lavigne&Gunnell 2006), species conservation (Iskandar*et al.* 2012), and many others. In terms of savanna ecosystem studies, remote sensing could provide further insights into the patterns of habitat fragmentation due to invasive alien species, as well as fires.

CONCLUSION

Remote sensing techniques were successfully applied to determine the expansion of the invasive plant species *Acacia nilotica* and the decrease in savanna area within Baluran National Park. The observation of the results of the Landsat image analysis showed that the savanna size has decreased by 1,361 ha, meanwhile, *A. nilotica* stand increased by 1,886 ha. Spatial distribution of *A. nilotica* in Baluran National Park shows a clumped pattern. *Acacia nilotica* which develops into a homogeneous stand in the north-west and eastern parts of the national park occupied an area of 3,628 ha or about 14.5% of the total area of Baluran National Park.

ACKNOWLEDGEMENTS

The authors acknowledge the Rufford foundation for conservation, Edith Cowan University, and Indonesian Institute of Sciences for the significant supports toward completion of the study. Baluran National Park's managers and rangers for kind supports and assistances.

REFERENCES

Abari AK, Nasr MH, Hodjati M, Bayat D, Radmehr M. 2012. Maximizing seed germination in two Acacia species. Journal of Forestry Research 23: 241-244.

Arno SF, Sneck KM, Forest I. 1977. USDA Forest Service General Technical Report : A method for determining fire history in coniferous forests of the mountain west. pp. 1-27. Intermountain Forest and Range Experiment Station, Forest Service, US Department of Agriculture, Ogden, Utah; Available from: https://www.fs.fed.us/rm/pubs_int/int_gtr042.pdf

Barata UW. 2000. *Biomasa, komposisi dan klasifikasi komunitas tumbuhan bawah pada tegakan Acacia nilotica di Taman Nasional Baluran, Jawa Timur* [Dissertation]. Retrieved from Gadjah Mada University Repository.

Barsi, J.A. Lee, K., Kvaran, G., Markham, B.L., & Pedelty, J.A. 2014. The Spectral Response of the Landsat-8 Operational Land Imager. Remote Sens., 6: 10232-10251.

Caesariantika E, Kondo T, Nakagoshi N. 2011. Impact of *Acacia nilotica* (L.) Willd. ex Del invasion on plant species diversity in the Bekol Savanna, Baluran National Park, East Java, Indonesia. Tropics,20: 45-54.

Chacón-Moreno EJ. 2004. Mapping savanna ecosystems of the Llanos del Orinoco using multitemporal NOAA satellite imagery. International Journal of Applied Earth Observation and Geoinformation5: 41-53.

Chuvieco E, Congalton RG. 1989. Application of remote sensing and geographic information systems to forest fire hazard mapping. Remote sensing of Environment 29: 147-159.

Djufri .2004. *Acacia nilotica* (L.) Willd. ex Del. *dan permasalahannya di Taman Nasional Baluran Jawa Timur* (*Acacia nilotica* (L.) Willd. ex Del. & its problems in Baluran National Park-East Java). BIODIVERSITAS5: 96-104.

Djufri. 2012. Analisis vegetasi pada savana tanpa tegakan *Acacia nilotica* di Taman Nasional Baluran Jawa Timur. Biologi Edukasi14: 104-111.

Gamasari AS. 2007. Mapping of habitat suitability for *Raflesia patma* using GIS application, [Skripsi]. Retrieved from Institut Pertanian Bogor repository.

Hudak A, Brockett B. 2004. Mapping fire scars in a southern African savannah using Landsat imagery. International Journal of Remote Sensing 25: 3231-3243.

Iskandar F, Iskandar E, Kyes RC. 2012. Populasi Owa Jawa (*Hylobates moloch*) di Taman Nasional Gunung Gede Pangrango, Jawa Barat. Jurnal Primatologi Indonesia6: 14-8.

Lavigne F, Gunnell Y. 2006. Land covers change and abrupt environmental impacts on Javan volcanoes, Indonesia: a long-term perspective on recent events. Regional Environmental Change6: 86-100.

Mabberley, DJ. 1997. The Plant-book: A Portable Dictionary of the Vascular Plants Utilizing Kubitzki's The Families and Genera of Vascular Plants (1990-), Cronquist's An Integrated System of Classification of Flowering Plants (1981), and Current Botanical Literature, Arranged Largely on the Principles of Editions 1-6 (1896/97-1931) of Willis's A Dictionary of the Flowering Plants and Ferns.Cambridge University Press.

Padmanaba, M., Tomlinson, K. W., Hughes, A. C., & Corlett, R. T. 2017. Alien plant invasions of protected areas in Java, Indonesia. *Scientific reports*, *7*(1), 9334.

Richards, J .A. 1999, Remote Sensing Digital Image Analysis, Springer-Verlag, Berlin, p. 240

Sabarno MY. 2002. Savana Taman Nasional Baluran. BIODIVERSITAS3: 207-212.

Sano EE, Rosa R, Brito JL, Ferreira LG. 2010. Land cover mapping of the tropical savanna region in Brazil. Environmental Monitoring and Assessment166: 113-124.

Schmidtlein S, Feilhauer H. Bruelheide H. 2012. Mapping plant strategy types using remote sensing. Journal of Vegetation Science23: 395-405.

Setiabudi, Tjitrosoediro S, Mawardi I, Bachri S. 2013. In 24th Asian-Pacific Weed Science Society Conference (eds B. Bakar, D. Kurniadi & S. Tjitrosoediro), pp. 144-150. BIOTROP, Bandung.

Siswoyo A. 2014. Pemodelan Spasial Kesesuaian Habitat Akasia Berduri (*Acacia nilotica*) di Taman Nasional Baluran. [Thesis] Retrieved from Institut Pertanian Bogor Repository.

Stroppiana D, Grégoire JM, Pereira JM .2003. The use of SPOT VEGETATION data in a classification tree approach for burnt area mapping in Australian savanna. International Journal of Remote Sensing 24: 2131-2151.

Sutomo, van Etten E, PriyadiA. 2015. Do Water Buffalo Facilitate Dispersal of Invasive Alien Tree Species Acacia nilotica in Bekol Savanna Baluran National Park? In *Second International Conference on Tropical Biology* (eds E. K. Damayanti & J. C. Fernandez), pp. 46. SEAMEO BIOTROP, Bogor.

Sutomo, van Etten E, Wahab L. 2016. Proof of Acacia nilotica stand expansion in Bekol Savanna, Baluran National Park, East Java, Indonesia through remote sensing and field observations. BIODIVERSITAS17: 96-101.

Tjitrosoedirdjo S. 2008. Invasive Species Database: Acacia nilotica. SEAMEO-BIOTROP South East Asian Regional Centre for Tropical Biology, Bogor; [updated 2013, cited 2018]; Available from: http://kmtb.biotrop.org/collections/spias/detail/2

Tjitrosoedirdjo S, Mawardi I, Setiabudi, Bachri S, Tjitrosoediro S. 2013. In 24th Asian-Pacific Weed Science Society Conference (eds B. Bakar, D. Kurniadi & S. Tjitrosoediro), pp. 246. BIOTROP, Bandung.

Van Etten E, Fox J. 2004. Vegetation classification and ordination of the central Hamersley Ranges, Western Australia. Journal of the Royal Society of Western Australia87: 63-79.

van Etten EJB. 1998. Mapping Vegetation in an Arid, Mountainous Region of Western Australia. Applied Vegetation Science1: 189-200.

Van Wilgen B, Biggs H, MareN, O'Regan S. 2000. A fire history of the savanna ecosystems in the Kruger National Park, South Africa, between 1941 and 1996. South African Journal of Science 96.4: 167-178.

VerlindenA, Laamanen R. 2006. Long term fire scar monitoring with remote sensing in northern Namibia: relations between fire frequency, rainfall, land cover, fire management and trees. Environmental Monitoring and Assessment112: 231–253.